Generating pitches in transients by a percussive excitation

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Abstract

Studying the excitation by percussion in the musical instruments universe, we make known a musical application of the physical modelling for sound synthesis. We have managed to generate pitches in the sound percussion transients. The percussion model employs a time rheologic representation postulating the Newtonian mechanics. We show, manipulating parameters in a modal analysis, how to get a pitch transient and how to tune the relative interval between the transient pitch and the pitch of stroked sound structure. We give a numerical application for a quinte transient. Some melodies sentences can be produce by adding successive strikers on the sound structure.

1. Introduction

Today, the computer offers to musicians a large catalogue of sound synthesis tools. When composers have to use a new synthesis tool, they often say: "can we control the hearing pitch with great accuracy ?" The attack transient of the real percussion sounds do not contain any hearing pitch. On the one hand, the duration of the transient is too short, on the other hand the transient spectra is near from noise spectra.

Using the CORDIS-ANIMA formalism for physical model simulation of vibrating systems, in the framework of a general sound synthesis tool, we study a striker model allowing a pitch perception of the attack transient.

Applying to a vibrant object a succession of percussive excitator elements, it is possible to synthesize transients of percussive sounds containing for example an arpeggio or a pentatonic scale.

2. Model of Percussion

The percussive object, in this physical model, is a punctual mass m2 (Cf. figure 1). The vibrating structure is a first-order oscillator O_1 with an inertia m_1, a stiffness K_1 and a viscosity Z_1. All movements are on a one dimensional space. An interaction between m_2 and O_1 is introduced as a repulsive force produced by a viscoelastic element of stiffness K_2 and viscosity Z_2. The interaction is such that $F = K_2(Y_p - Y_O) + Z_2(\dot{Y}_p - \dot{Y}_O)$ if $Y_p < Y_O$, $F = 0$ otherwise (eq. 1). Yp is the altitude of the mass m_2; Y_O is the altitude of the vibrating structure impact mass.

The striker mass is shot with an initial velocity and O_1 is initially at rest. The percussion model has been studied exhaustively in **[Fourcade and Cadoz 1996]**.

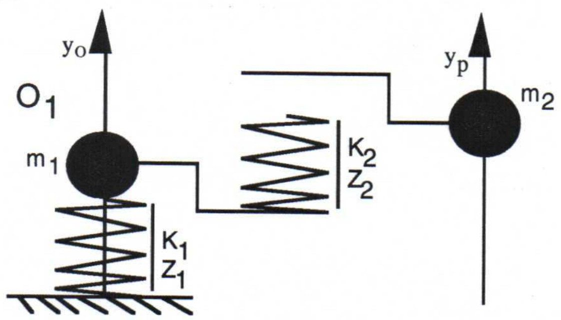

Figure 1 - *Model of percussion. The mass m_2 strikes the mass m_1 of the O_1 oscillator, with the interaction law:* $F = K_2(Y_p - Y_O) + Z_2(\dot{Y}_p - \dot{Y}_O)$ *if* $Y_p < Y_O$, $F = 0$ *otherwise*

3. Pitches and Modal Analysis

When the striker mass altitude, Yp, is smaller than the oscillator mass altitude, Y_O, the system is on a transient phase.

We studied the frequency modes of the system during its transient phase (linked system). The viscosity Z_1 and Z_2 are neglected. We note

$f_1 = \frac{1}{2\pi}\sqrt{\frac{k_1}{m_1}}$ and $f_2 = \frac{1}{2\pi}\sqrt{\frac{k_2}{m_2}}$. If we note F_+ and F_- the owners frequencies of the linked system, introducing for convenience the variable γ, $\gamma = \frac{m_1 + m_2}{m_1}$, it comes:

$$\text{(eq. 2)} \quad \begin{cases} F_+^2 = \frac{1}{2}\left[f_1^2 + \gamma f_2^2 + \sqrt{\Delta}\right] \\ F_-^2 = \frac{1}{2}\left[f_1^2 + \gamma f_2^2 - \sqrt{\Delta}\right] \\ \Delta = \left(f_1^2 + \gamma f_2^2\right)^2 - 4 f_1^2 f_2^2 \\ \gamma = \left(1 + \frac{m_2}{m_1}\right) \end{cases}$$

Because of the non-linearity condition, F₋ mode will not be perceived as a pitch. Except indeed in a specific case (high rate m_2/m_1 and strong stiffness K_2), the interaction has got only one contact and the striker runs away. So, the linked phase duration is quite $F_-/2$, an oscillation half period. This mode acts upon the rise-time (time duration between the min and the max amplitude reached in the transient signal).

Parameters m_1, f_1, F_+ and F_- define the model on the frequency space. We determine others system parameters from m_1, f_1, F_+ and F_-. Observing from (eq. 2) that $f_1 f_2 = F_- F_+$ and that $f_1^2 + \gamma f_2^2 = F_-^2 + F_+^2$, we have:

$$\text{(eq. 3)} \quad \begin{cases} \gamma = \frac{f_1^2}{F_+^2} + \frac{f_1^2}{F_-^2} - \frac{f_1^4}{F_-^2 F_+^2} \\ f_2 = \frac{F_- F_+}{f_1} \\ m_2 = m_1(\gamma - 1) \\ \frac{F_-}{F_+} > c \text{ ou } \frac{F_-}{F_+} < b \\ F_- < f_1 < F_+ \end{cases}$$

b and c are constant, function of γ:

$$b = \sqrt{2\gamma - 1 - 2\sqrt{\gamma^2 - \gamma}}$$

and $c = \sqrt{2\gamma - 1 + 2\sqrt{\gamma^2 - \gamma}}$.

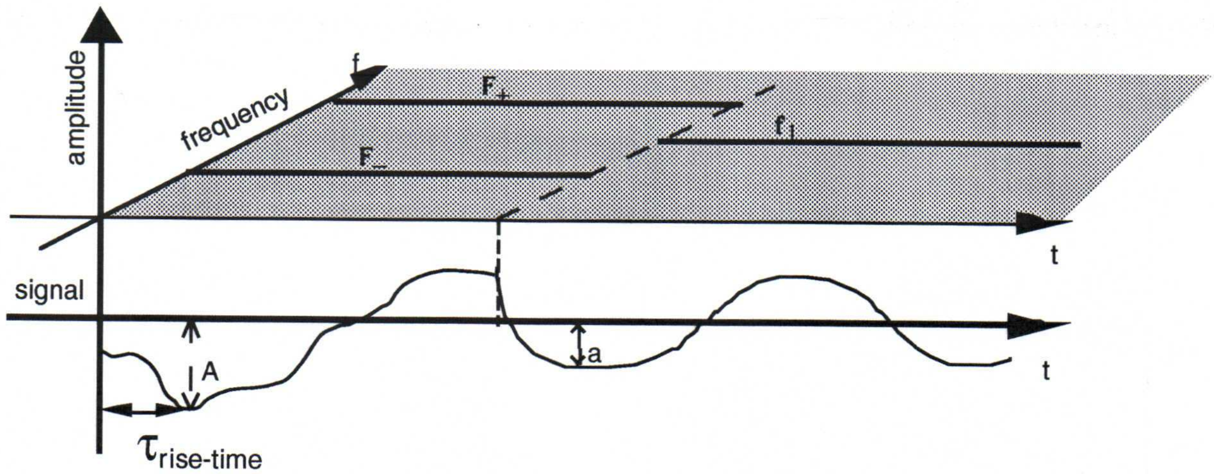

Figure 2 - *Example of a "percussive" attack grain on an harmonic oscillator. Frequencies result from an analytic modal analysis*

4. The CORDIS-ANIMA formalism

The CORDIS-ANIMA system developed at the ACROE **[Cadoz, et al. 1993]** allows the computer-based modelling and simulation of physical objects that can be seen, heard and handled (with force-feedback gestural control device). An object is a modular assembly of elementary mechanical components picked up amongst a limited number of types with very simple associated elementary simulation algorithms. The description is based on the fundamental laws of Newtonian Mechanics.

The percussion model has been realised thanks to CORDIS-ANIMA for computer simulations and synthesized sounds.

5. Numerical Application: a quinte transient

It is possible to create an attack which generates the pitch intervals perception from:
- the oscillator's inertia m_1,
- the resonance frequency f_1,
- the frequency rate between F_+ and F_1 (interval),
- the number N of F_+ mode periods during the transient phase.

In the case of a quinte percussion E5-A4, we give $m_1 = 1$Kg, $f_1 = 440$Hz, N high enough to perceive a pitch, N = 10 and $F_+/f_1 = 1.5$ (quinte of the Pythagorean scale). We want $F_- \approx F_+/2N$. So, $F_+ = 660$Hz and $F_- = 33$Hz.

From (eq. 3), we obtain $\gamma = 20.1975$,

$m_2 = 19.1975$Kg, $f_2 = 49.5$Hz.

Explaining with stiffness, we have $k_2 = 4\pi^2 f_2^2 m_2$;

we obtain $k_2 = 1.8573E6Nm^{-1}$;

same here, $k_1 = 7.6412E6Nm^{-1}$.

By applying the formula for simulation algorithm parameters (algo suffix), that take into account the time quantification and the causal algorithms necessity, neglecting the oscillator viscosity effect, we have:

$$f = \frac{Fe}{2\pi}\cos^{-1}\left(1 - \frac{K_{algo}}{2M_{algo}}\right),$$

$m = M_{algo}$ with Fe = 44100Hz

(cf. **[Incerti 1996]**).

Thus, finally we have $K_{1algo} = 3.929E-3$ and $K_{2algo} = 9.55E-4$. The resulting sound has the following reference [Sound example A].

6. Play with Pitch transients

We made a serie of elementary percussions. Adding to the three parameters (m_i, k_i, v_i) describing one striker i with inertia m_i, stiffness k_i, and velocity v_i, we get T_i, the time when striker i reaches the 0 altitude without the oscillator presence. We note N the total number of strikers.

From the equations system showed in (eq. 3), it is possible, neglecting the viscosity influence, to build attacks that induce pitch variations.

In the sound example [Sound example B], a major arpeggio is perceived; we can listen successively B3, G#3, and E3.

In the same manner, in the example [Sound example C], we perceived a melody in arch at the attack; it listens successively at three octave: G#, A, A#, B, A#, A, G# and E.

7. Singular Sounds

It is difficult to make expectations on the oscillator behaviour after a percussion. One oscillator can be stop moving with the last percussion in a series (cf. [Sound example D]).

Viscosity of the striker can operates in a particular case modifying the transient pitch (cf. [Sound example E]). This phenomenon appears for a light striker's inertia ($m_1/10$) and a weak stiffness link ($k_1/100$). The perceived attack pitch is lightly under the oscillator pitch (70 cents). The striker mass stays a long time (50 ms) under the oscillator mass and vibrates in cooperation with it. Timbre evokes drop water.

References

[Fourcade and Cadoz 1996] P. Fourcade and C. Cadoz, *"Sound Synthesis by Physical Modelling : an Elementary Striker,"* presented at Forum Acusticum, Antwergen, 1996.

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